CLAIMS

[Claim 1] A method for assessing the remaining service life of a rolling bearing, characterized in comprising:

baseline data acquisition means for obtaining vibration signals by using an accelerometer (4) and using a testing device to acquire signals in a frequency band that includes resonance frequency band signals detectable at the highest sensitivity, for each specification such as model number, manufacturer name, and other specifications for a rolling bearing (3) as pertains to the relationship between the state of wear particle penetration in the rolling bearing (3) and the vibration/bearing service life, and to lubricant degradation and vibration/bearing service life;

measurement means whereby an accelerometer (4) is used to obtain vibration signals for the rolling bearing (3) whose remaining service life is being assessed and which resides on a fan, a pump, or another rotating device (1, 2), for the purpose of measuring signals in a frequency band that includes resonance frequency band signals detectable at the highest sensitivity; and

determination means for estimating the state of wear particle penetration and the state of lubricant degradation of said diagnostic rolling bearing (3), and computing the remaining service life of said diagnostic rolling bearing (3) by using measurement values obtained by said measurement means, determination results relating to said bearing specifications, and data obtained by said baseline data acquisition means.

[Claim 2] The method for assessing the remaining service life of a rolling bearing according to claim 1, characterized in that said determination means computes the remaining service life of the rolling bearing (3) using the calculated service life of said rolling bearing (3) and vibration values computed as a result of processing the measured waveform of vibration of said diagnostic rolling bearing (3).

[Claim 3] The method for assessing the remaining service life of a rolling bearing according to claim 1, characterized in that said determination means makes a determination regarding the model number, manufacturer name, and other bearing specifications for said diagnostic rolling bearing (3) after dividing the vibration waveform at 1 kHz to 6 kHz into 1/2-octave frequency bands to obtain a plurality of bands for said diagnostic rolling bearing (3), performing envelope processing for the waveforms of each frequency band, and computing a frequency spectrum.

[Claim 4] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 3, characterized in that said determination means divides the vibration waveform at 1 kHz to 64 kHz into 1/2-octave frequency bands to obtain a plurality of bands for said diagnostic rolling bearing (3), performs envelope processing for the waveforms of each frequency band, computes a frequency spectrum, and makes a determination regarding the model number, manufacturer name, and other bearing specifications; and

when the model number and manufacturer name of said diagnostic rolling bearing (3) are determined,

a bearing pass frequency is calculated from the bearing specifications, pass frequency components (the three components f_{inn}, f_{out}, f_{ball}) are extracted from the enveloped spectrum of each frequency band, relative sensitivities (ratios to normal) of the extracted pass frequency components in each frequency band are computed, and the relative sensitivities of the pass frequency components are averaged over the upper bands selected from the divided data bands;

a determination is made as to whether any of the upper-band averages of the pass frequency components in the divided bands exceed a threshold value; and

an estimation of "normal" is made when the threshold value is not exceeded.

[Claim 5] The method for assessing the remaining service life of a rolling bearing according to claim 4, characterized in that

in said determination means, the vibration waveform at 5 kHz to 35 kHz is divided into 1/2-octave frequency bands to obtain a total of 6 bands for said diagnostic rolling bearing (3), envelope processing is performed for the waveforms of each frequency band, and a frequency spectrum is computed.

[Claim 6] The method for assessing the remaining service life of a rolling bearing according to claim 4, characterized in that the threshold value in said determination means is a number greater than 1.

[Claim 7] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 3, characterized in that said determination means

divides the vibration waveform at 1 kHz to 64 kHz into 1/2-octave frequency bands to obtain a plurality of bands for said diagnostic rolling bearing (3);

performs envelope processing for the waveforms of each frequency band, computes a frequency spectrum; and

makes a determination regarding the model number, manufacturer name, and other bearing specifications; and

when the model number and manufacturer name of said diagnostic rolling bearing (3) are determined,

a frequency spectrum peak in the range of 1.6-7 times the rotational speed is extracted from the enveloped spectrum of each frequency band;

relative sensitivities (ratios to normal) of the peak frequency components of each extracted frequency band are computed;

the relative sensitivities of the peak frequency components are averaged over the top three bands;

a determination is made as to whether the relative sensitivity average of the upper bands obtained by dividing peak frequency components exceeds a threshold value; and

an estimation of "normal" is made when the threshold value is not exceeded.

[Claim 8] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 3,

characterized in that said determination means divides the vibration waveform at 1 kHz to 64 kHz into 1/2-octave frequency bands to obtain a total of 6 bands for said diagnostic rolling bearing (3);

performs envelope processing for the waveforms of each frequency band to compute a frequency spectrum; and

makes a determination regarding the model number, manufacturer name, and other bearing specifications; and

when the model number and manufacturer name of said diagnostic rolling bearing (3) are not determined,

a frequency spectrum peak in the range of 1.6-7 times the rotational speed is extracted from the enveloped spectrum of each frequency band;

relative sensitivities (ratios to normal) of the peak frequency components of each extracted frequency band are computed and the relative sensitivities of the peak frequency components are averaged over the top three bands; and

a determination is made as to whether the relative sensitivity average the peak frequency components over the top three bands exceeds a threshold value.

[Claim 9] The method for assessing the remaining service life of a rolling bearing according to claim 7 or 8, characterized in that the threshold value in said determination means is a number greater than 1.

[Claim 10] A method for assessing the remaining service life of a rolling bearing, characterized in comprising:

baseline data acquisition means for obtaining vibration signals by using an accelerometer (4) and using a testing device to acquire signals in a frequency band that includes resonance frequency band signals detectable at the highest sensitivity, as pertains to the relationship between the state of wear particle penetration in a rolling bearing (3) and the vibration/bearing service life, and to lubricant degradation and vibration/bearing service life;

measurement means whereby an accelerometer (4) is used to obtain vibration signals for the rolling bearing (3) whose remaining service life is being assessed and which resides on a fan, a pump, or another rotating device (1, 2), for the purpose of measuring signals in a frequency band that includes resonance frequency band signals detectable at the highest sensitivity; and

determination means for estimating the state of wear particle penetration and the state of lubricant degradation of said diagnostic rolling bearing (3), and computing the remaining service life of said diagnostic rolling bearing (3) by using measurement values obtained by said measurement means, and data obtained by said baseline data acquisition means.

[Claim 11] The method for assessing the remaining service life of a rolling bearing according to claim 10, characterized in that said determination means

calculates the relative sensitivity of an effective value in two frequency bands, which are a wide band and a narrow band that includes the sensor resonance frequency band, from

vibration signals having a frequency band of 1 kHz to 64 kHz for said diagnostic rolling bearing (3);

determines whether a quantitative feature that is the product of the relative sensitivity of a narrow-band effective value and the relative sensitivity of the wide-band effective value exceeds a threshold value; and

makes a determination of "normal" when the threshold value is not exceeded.

[Claim 12] The method for assessing the remaining service life of a rolling bearing according to claim 10, characterized in that said determination means

calculates the relative sensitivity of an effective value in the two frequency bands of 23 kHz to 32 kHz and 5 kHz to 35 kHz from vibration signals having a frequency band of 5 kHz to 35 kHz for said diagnostic rolling bearing (3);

determines whether a quantitative feature that is the product of the relative sensitivity of the effective value at 23 kHz to 32 kHz and the relative sensitivity of the effective value at 5 kHz to 35 kHz exceeds a threshold value; and

makes a determination of "normal" when the threshold value is not exceeded.

[Claim 13] The method for assessing the remaining service life of a rolling bearing according to claim 11 or 12, characterized in that the threshold value in said determination means is a number greater than 1.

[Claim 14] The method for assessing the remaining service life of a rolling bearing according to claim 4 or 10, characterized in that

in said determination means, it is determined for said diagnostic rolling bearing (3) whether any of the upper-band averages of the pass frequency components in the divided bands exceed a threshold value; and

when the threshold value is exceeded,

a wavelet distribution of the vibration waveform is created in order to prevent misidentification of indentation/lubricant degradation;

the time frequency distribution (wavelet) is displayed; and

the time frequency distribution (wavelet) is confirmed by a human.

[Claim 15] The method for assessing the remaining service life of a rolling bearing according to claim 7 or 10, characterized in that

in said determination means, it is determined for said diagnostic rolling bearing (3) whether the relative sensitivity average the peak frequency components over the top three bands exceeds a threshold value, and when the threshold value is exceeded,

a wavelet distribution of the vibration waveform is created in order to prevent misidentification of indentation/lubricant degradation;

the time frequency distribution (wavelet) is displayed; and

the time frequency distribution (wavelet) is confirmed by a human.

[Claim 16] The method for assessing the remaining service life of a rolling bearing according to claim 10, characterized in that

in said determination means, it is determined for said diagnostic rolling bearing (3) whether the product of the relative sensitivity of a wide-band effective value and the relative sensitivity of a narrow-band effective value exceeds a threshold value, and when the threshold value is exceeded,

a wavelet distribution of the vibration waveform is created in order to prevent misidentification of indentation/lubricant degradation;

the time frequency distribution (wavelet) is displayed; and

the time frequency distribution (wavelet) is confirmed by a human.

[Claim 17] The method for assessing the remaining service life of a rolling bearing according to claim 2, characterized in that the remaining service life in the cases of indentation-induced lubricant degradation and fatigue flaking is assessed in said determination means using a residual service life estimation equation computed as the product of the calculated service life and a residual service life coefficient from 0 to 1.

[Claim 18] The method for assessing the remaining service life of a rolling bearing according to claim 4, characterized in that a determination is made in said determination means for said diagnostic rolling bearing (3) whether any of the upper-band averages of the pass frequency components in the divided bands exceed a threshold value, and when the threshold value is exceeded,

the case of indentation-induced fatigue flaking is confirmed;

the indentation size is estimated from the relative sensitivity average of the top three bands; and

the remaining service life in the case of indentation-induced fatigue flaking is calculated and assessed according to the equation [Eq. (1)] below.

[Eq. (1)]

$$L_{10} = L_{10h} \times 10^{(0.0038d\log(P/C)-0.272\log(d)+0.416)}$$

[Claim 19] The method for assessing the remaining service life of a rolling bearing according to claim 7, characterized in that a determination is made in said determination means for said diagnostic rolling bearing (3) whether the relative sensitivity average the peak frequency components over the top three bands exceeds a threshold value, and when the threshold value is exceeded,

the case of indentation-induced fatigue flaking is confirmed;

the indentation size is estimated from the relative sensitivity average of the top three bands; and

the remaining service life in the case of indentation-induced fatigue flaking is calculated and assessed according to the equation [Eq. (1)] below.

[Eq. (1)]

$$L_{10} = L_{10h} \times 10^{(0.0038d\log(P/C)-0.272\log(d)+0.416)}$$

[Claim 20] The method for assessing the remaining service life of a rolling bearing according to claim 17, characterized in that in said determination means, the equation for estimating the remaining service life in the case of indentation-induced fatigue flaking is defined by letting the calculated service life be the basic dynamic service life rating in the equation [Eq. (2)] below, and letting the residual service life coefficient be the occurrence of indentations as a function of P/C and a vibration value.

[Eq. (2)]

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^3$$

[Claim 21] The method for assessing the remaining service life of a rolling bearing according to claim 17, characterized in that in said determination means, the equation for estimating the remaining service life in the case of lubricant

degradation is defined by letting the calculated service life be the calculated service life according to the equation [Eq. (3)] below, and letting the residual service life coefficient be the residual service life based on the occurrence of lubricant degradation as a function of the vibration value.

[Eq. (3)]

$$\log(L_{hb}) = -2.30 + \frac{2450}{273+t} - 0.301(S_G + S_N + S_W)$$

[Claim 22] The method for assessing the remaining service life of a rolling bearing according to claim 10, characterized in that said determination means

computes for said diagnostic rolling bearing (3) the relative sensitivity of an effective value in the sensor resonance frequency band of 23 kHz to 32 kHz and an effective value at 5 kHz to 35 kHz; and

determines whether the product of the relative sensitivity of the effective value at 23 kHz to 32 kHz and the relative sensitivity of the effective value at 5 kHz to 35 kHz exceeds a threshold value; and

when the threshold value is exceeded,

the case of lubricant degradation is confirmed; and

the remaining service life in the case of lubricant degradation is calculated and assessed according to the equation [Eq. (4)] below from the relative sensitivity of the effective value at 23 kHz to 32 kHz.

[Eq. (4)]

$$L = L_{hb} \times V_r^{-4.44}$$

[Claim 23] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10, characterized in that said determination means

computes a cepstrum of a vibration waveform at 1 kHz to 64 kHz for said diagnostic rolling bearing (3);

computes the kurtosis of the cepstrum;

determines whether the kurtosis of the cepstrum exceeds a threshold value;

determines that the case of indentation-induced fatigue flaking is in effect when the threshold value is exceeded; and

assesses that the case of lubricant degradation is in effect when the threshold value is not exceeded.

[Claim 24] The method for assessing the remaining service life of a rolling bearing according to claim 23, characterized in that the threshold value in said determination means is a number greater than 3.

[Claim 25] The method for assessing the remaining service life of a rolling bearing according to claim 1, 10, or 11, characterized in that

when the presence of a defect of lubricant degradation or indentation-induced fatigue flaking is determined in said determination means,

assessment by a human is deemed unnecessary, and a time frequency distribution (wavelet) is not displayed.

[Claim 26] The method for assessing the remaining service life of a rolling bearing according to claim 5 or 8, characterized in that

when a determination is made in said determination means that the case of indentation-induced fatigue flaking is in effect and said threshold value is exceeded for said diagnostic rolling bearing (3),

the indentation size is estimated from the relative sensitivity average of the top three bands;

the remaining service life in the case of indentation-induced fatigue flaking is assessed;

and the remaining service life is expressed in units of time.

[Claim 27] The method for assessing the remaining service life of a rolling bearing according to claim 11, characterized in that when a determination is made in said determination means that the case of lubricant degradation is in effect and said threshold value is not exceeded for said diagnostic rolling bearing (3),

severity of lubricant degradation is estimated from the effective value of said diagnostic rolling bearing (3) at 23 kHz to 32 kHz;

the remaining service life in the case of lubricant degradation is assessed; and

the remaining service life is expressed in units of time.

[Claim 28] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10,

characterized in that the band of 5 kHz to 35 kHz is divided into 6 frequency bands and an enveloped spectrum is computed in said determination means for said diagnostic rolling bearing (3) in order to detect indentations for measuring the vibration waveform at 5 kHz to 35 kHz;

a determination is made as to whether the enveloped spectrum exceeds a threshold value; and

an estimation of "normal" is made when the threshold value is not exceeded; and

when the threshold value is exceeded, a defect is estimated to be present even though the type of defect/failure cannot be specified for the case of indentation-induced fatigue flaking.

[Claim 29] The method for assessing the remaining service life of a rolling bearing according to claim 10, characterized in that in said determination means, a quantitative feature (product of an effective value at 23 kHz to 32 kHz and an effective value at 5 kHz to 35 kHz) is computed in order to detect lubricant degradation for said diagnostic rolling bearing (3);

a determination is made as to whether the quantitative feature of the lubricant degradation exceeds a threshold value; and

an estimation of "normal" is made when the threshold value is not exceeded; and

when the threshold value is exceeded, a defect is estimated to be present even though the type of defect/failure cannot be specified for the case of lubricant degradation.

[Claim 30] The method for assessing the remaining service life of a rolling bearing according to claim 29 or 30, characterized in that the threshold value in said determination means is 2.0.

[Claim 31] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10, characterized in that in said determination means, a quantitative feature (kurtosis of the cepstrum) for said diagnostic rolling bearing (3) is computed in order to distinguish between indentations and lubricant degradation, and a determination is made as to whether the kurtosis of the cepstrum exceeds a threshold value; and

when the threshold value is exceeded, a determination is made that there is a defect of indentation-induced fatigue flaking; and

when the threshold value is not exceeded, an estimate is made that there is a defect of lubricant degradation.

[Claim 32] The method for assessing the remaining service life of a rolling bearing according to claim 31, characterized in that the threshold value in said determination means is 3.8.

[Claim 33] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10, characterized in that a determination is made in said determination means that the diagnostic rolling bearing (3) is

normal when the result of detecting indentations for the diagnostic rolling bearing (3) does not exceed a threshold value, and the result of detecting lubricant degradation also does not exceed a threshold value.

[Claim 34] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10, characterized in that

a need for caution is recognized;

the amount of indentations, the amount of lubricant degradation, and the identified amount of indentations/lubrication are specified; and

a time frequency distribution (wavelet) is displayed in said determination means when the type of failure cannot be specified and the result of detecting indentations for the diagnostic rolling bearing (3) exceeds a threshold value, or when the type of failure cannot be specified and the result of detecting lubricant degradation exceeds a threshold value; and

the type of failure is determined and assessed by a human.

[Claim 35] The method for assessing the remaining service life of a rolling bearing according to claim 1, 2, or 10, characterized in that

a determination is made in said determination means that there is a defect of indentation-induced fatigue flaking;

a determination is made that indentation has occurred; and

the remaining service life in the case of indentation-induced fatigue flaking is assessed when the result of

detecting indentations for the diagnostic rolling bearing (3) exceeds a threshold value, and the kurtosis of the cepstrum exceeds a threshold value.

[Claim 36] The method for assessing the remaining service life of a rolling bearing according to claim 11, characterized in that

a determination is made in said determination means that there is a defect of lubricant degradation;

a determination is made that lubricant degradation has occurred; and

the remaining service life in the case of lubricant degradation is assessed when the result of detecting lubricant degradation for the diagnostic rolling bearing (3) exceeds a threshold value, and the kurtosis of the cepstrum does not exceed a threshold value.

[Claim 37] The method for assessing the remaining service life of a rolling bearing according to claim 1, 10, or 11, characterized in that

a need for caution is recognized;

the amount of indentations, the amount of lubricant degradation, and the identified amount of indentations/lubrication are specified;

a time frequency distribution (wavelet) is displayed; and

the type of failure is determined and assessed by a human in said determination means when there is a defect of indentation-induced fatigue flaking, or a determination is

made that there is a defect of lubricant degradation in the diagnostic rolling bearing (3).

[Claim 38] The method for assessing the remaining service life of a rolling bearing according to claim 6, 9, 13, or 24, characterized in that the threshold value for detecting indentations and lubricant degradation in said determination means is varied according to (a) the BRG size, (b) machine weight, (c) electric motor output, (d) machine type, and (e) a combination of factors (a) through (d).

[Claim 39] The method for assessing the remaining service life of a rolling bearing according to claims 1 through 38, characterized in further comprising conventional failure detection means for assessing machine unbalance and misalignment, loose substructures, and the like by frequency analysis in addition to detecting indentations and lubricant degradation in said determination means for comprehensively assessing all rotating machine failures.

[Claim 40] A device for assessing the remaining service life of a rolling bearing, characterized in comprising:

an accelerometer (4) for measuring vibration signals relating to a diagnostic rolling bearing (3) whose remaining service life is being assessed;

an analog/digital converter (5) for converting data obtained via said accelerometer (4);

a quantitative feature extraction unit (6) for extracting characteristics of indentation and lubricant degradation from

vibration signals converted by said analogue/digital converter (5);

a measurement results database (7) in which are stored baseline data that records the relationship of wear particle penetration to vibration and bearing service life, and the relationship of lubricant degradation to vibration and bearing service life in the rolling bearings (3); vibration data obtained during normal fatigue of the diagnostic rolling bearing (3) residing on a mechanical rotating device (1, 2), such as a pump or fan; and data related to bearing load, speed of rotation, operating time, and rolling bearing designation;

a residual service life assessment unit (8) that, utilizing data stored in said measurement results database (7), determines wear particle penetration levels and lubricant degradation levels in said diagnostic rolling bearing (3) on the basis of vibration signals from said diagnostic rolling bearing (3) extracted via said quantitative feature extraction unit (6) to assess residual service life; and

an assessment results display (9) for displaying the results from said residual service life assessment unit (8).